PHOTOCURRENT-TO-BINARY SIGNAL CONVERSION APPARATUS CAPABLE OF SUPPRESSING WAVEFORM DISTORTION

BACKGROUND OF THE INVENTION

5   Field of the Invention

The present invention relates to a photocurrent-to-binary signal conversion apparatus capable of suppressing waveform distortion.

Description of the Related Art

10   Generally, in order to electrically insulate an input from an output in factory automation (FA) or the like, a photocoupler has been developed. In such a photocoupler, a photocurrent-to-binary conversion apparatus is used. Also, a photocurrent-to-binary signal conversion apparatus is used in

15   a light receiving circuit in infrared communication or optical cable communication. Further, a photocurrent-to-binary signal conversion apparatus is used in a light detection circuit for converting a laser reflection signal into an electrical digital signal of an optical disc unit.

20   A prior art photocurrent-to-binary signal conversion apparatus is constructed by a light receiving element for receiving a light signal so that a photocurrent in response to the light signal flows therethrough, an amplifier for converting the photocurrent into a detection voltage, a

25   reference voltage generating circuit for offsetting an input voltage of the amplifier on the side of this input voltage to generate a reference voltage, a time constant circuit including voltage dividing resistors and a capacitor between the output of the amplifier and the output of the reference

30   voltage generating circuit to generate a threshold voltage, and a comparator for comparing the detection voltage with the threshold voltage to generate a binary signal (see: U.S. Patent No. 5,061,859). This will be explained later in detail.

In the above-described prior art photocurrent-to-binary signal conversion apparatus, however, waveform distortion between a photocurrent and a binary signal and waveform distortion between different binary signals corresponding to different levels of photocurrents are generated.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a photocurrent-to-binary signal conversion apparatus capable of suppressing the waveform distortion.

According to the present invention, in a photocurrent-to-binary signal conversion apparatus, a light receiving element receives a light signal so that a photocurrent in response to the light signal flows through the light receiving element. An amplifier converts the photocurrent into a detection voltage. A reference voltage generating circuit offsets the detection voltage on the side of the detection voltage to generate a reference voltage. A comparator compares the detection voltage with the reference voltage to generate a binary signal in according with whether or not the detection voltage is higher than the reference voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more clearly understood from the description set forth below, as compared with the prior art, with reference to the accompanying drawings, wherein:

Fig. 1 is a circuit diagram illustrating a prior art photocurrent-to-binary signal conversion apparatus;

Figs. 2A, 2B, 2C, 2D, 3A, 3B, 4A and 4B are timing diagrams for explaining the operation of the photocurrent-to-binary

signal conversion apparatus of Fig. 1;

Fig. 5 is a circuit diagram illustrating a first embodiment of the photocurrent-to-binary signal conversion apparatus according to the present invention;

5 Figs. 6A, 6B, 6C, 7A, 7B, 8A and 8B are timing diagrams for explaining the operation of the photocurrent-to-binary signal conversion apparatus of Fig. 5; and

Fig. 9 is a circuit diagram illustrating a second embodiment of the photocurrent-to-binary signal conversion
10 apparatus according to the present invention;

Figs. 10A and 10B are detailed circuit diagrams of the amplifier of Fig. 9; and

Fig. 11 is a circuit diagram illustrating a third embodiment of the photocurrent-to-binary signal conversion
15 apparatus according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before the description of the preferred embodiments, a prior art photocurrent-to-binary signal conversion
20 apparatus will be explained with reference to Fig. 1, 2A, 2B, 2C, 2D, 3A, 3B, 4A and 4B.

In Fig. 1, which illustrates a prior art photocurrent-to-binary signal conversion apparatus (see: U.S. Patent No. 5,061,859), reference numeral 1 designates a
25 photodiode having a grounded anode and a cathode. When the photodiode 1 receives a light signal, a photocurrent I_{pd} flows from the cathode to the anode.

An amplifier 2 is connected to the cathode of the photodiode 1. The amplifier 2 converts the photocurrent I_{pd}
30 into a detection voltage V_d. The amplifier 2 is constructed by an operational amplifier 21 having a grounded non-inverting input and an inverting input connected to the photodiode 1, and a negative feedback resistor 22 connected between the

output and inverting input of the operational amplifier 21.

A reference voltage generating circuit 3 is connected to the cathode of the photodiode 1. That is, the reference voltage generating circuit 3 offsets a voltage V_c at the cathode of the photodiode 1 on the side of the voltage V_c to generate a reference voltage V_{ref}. The reference voltage generating circuit 3 is constructed by an operational amplifier 31 having a non-inverting input connected to the cathode of the photodiode 1, a negative feedback resistor 32 connected between the output and inverting input of the operational amplifier 31, and a constant current source 33 having an end connected to the inverting input of the operational amplifier 31 and the negative feedback resistor 32 and a grounded end.

A time constant circuit 4 divides a difference between the detection voltage V_d of the amplifier 2 and the reference voltage V_{ref} to generate a threshold voltage V_{th}. The time constant circuit 4 is constructed by voltage dividing resistors 41 and 42 connected in series between the output of the amplifier 2 and the output of the reference voltage generating circuit 3, and a capacitor 43 connected to a node between the voltage dividing resistors 41 and 42. For example, the voltage dividing ratio by the voltage dividing resistors 41 and 42 is 1:2.

A comparator 5 compares the detection voltage V_d of the amplifier 2 with the threshold voltage V_{th} of the time constant circuit 4 to generate a binary signal S in accordance with whether or not the detection signal V_d is higher than the threshold voltage V_{th}.

In Fig. 1, when no light signal is incident to the photodiode 1, no photocurrent I_{pd} flows therethrough. As a result, in the amplifier 2, since no current flows through the negative feedback resistor 22, the detection voltage V_d is the

same as the voltage V_c at the cathode of the photodiode 1. In this case,

$$V_d = V_c = V_{os1}$$

where V_{os1} is an offset voltage of the operational amplifier 21 depending the current of a constant current source (see: 211a of Fig. 10A) therein. Also, in the reference voltage generating circuit 3, since the negative feedback resistor 32 and the constant current source 33 generate an offset voltage V_{os2}, the offset voltage V_{os2} is applied to the voltage V_c at the photodiode 1, so that the reference voltage V_{ref} is given by

$$V_{ref} = V_{os1} + V_{os2}$$

As a result, in the time constant circuit 4, the threshold voltage V_{th} is given by

$$V_{th} = (V_d \cdot 1 + V_{ref} \cdot 2) / 3$$
$$= 2(V_{os1} + V_{os2}) / 3$$

Thus, in the comparator 5, since $V_d < V_{th}$, the binary signal S is low (="0").

In Fig. 1, when a light signal is incident to the photodiode 1, a current I_{pd} flows therethrough. As a result, in the amplifier 2, the current I_{pd} flows through the negative feedback resistor 22, so that the detection voltage V_d is given by

$$V_d = V_c + I_{pd} \cdot R_f$$

where R_f is a resistance of the negative feedback resistor 22. In this case, since $V_c < V_{os1}$,

$$V_d < V_{os1} + I_{pd} \cdot R_f$$

Also, in the reference voltage generating circuit 3, the offset voltage V_{os2} is applied to the voltage V_c, so that the reference voltage V_{ref} is given by

$$V_{ref} < V_{os1} + V_{os2}$$

As a result, in the time constant circuit 3,

$$V_{th} = (V_d \cdot 1 + V_{ref} \cdot 2) / 3$$

$$< V_{os1} + I_{pd} \cdot R_f + 2 \cdot V_{os2} / 3$$

Thus, in the comparator 5, since $V_d > V_{th}$, the binary signal S is high (="1").

The operation of the photocurrent-to-binary signal conversion apparatus of Fig. 1 will be explained next with reference to Figs. 2A, 2B, 2C, 2D, 3A, 3B, 4A and 4B where two different photocurrents I_{pd1} and I_{pd2} ($> I_{pd1}$) flow through the photodiode 1 as shown in Fig. 2A.

As shown in Fig. 2B, detection voltages V_{d1} and V_{d2} in response to the photocurrents I_{pd1} and I_{pd2}, respectively, are outputted from the amplifier 2.

As shown in Fig. 2C, the voltage V_c at the cathode of the photodiode 1 is decreased. In this case, a voltage V_{c2} at $I_{pd} = I_{pd2}$ is lower than a voltage V_{c1} at $I_{pd} = I_{pd1}$. Therefore, as shown in Fig. 2D, since the offset voltage V_{os2} is applied to the reference voltage V_{ref}, a reference voltage V_{ref2} at $I_{pd} = I_{pd2}$ is lower than a reference voltage V_{ref1} at $I_{pd} = I_{pd1}$.

Therefore, as shown in Fig. 2E, a threshold voltage V_{th1} at $I_{pd} = I_{pd1}$ and a threshold voltage V_{th2} at $I_{pd} = I_{pd2}$ are obtained from the detection voltage V_{d1} and V_{d2} as shown in Fig. 2B and the reference voltages V_{ref1} and V_{ref2} as shown in Fig. 2D.

When the photocurrent I_{pd1} flows through the photodiode 1, the detection voltage V_{d1} crosses the threshold voltage V_{th1} at an acute angle as shown in Fig. 3A. Therefore, as shown in Fig. 3B, a falling time t_{df1} is longer than a rising time t_{dr1} due to the time constant circuit 4. As a result, a time period T_1 of high level (="1") of the binary signal S is longer than a time period T_0 of a high level of the photocurrent I_{pd}.

Also, when the photocurrent I_{pd2} flows through the photodiode 1, the detection voltage V_{d2} crosses the threshold

voltage V_{th1} at an acute angle as shown in Fig. 4A. Therefore, as shown in Fig. 4B, a falling time t_{df2} is longer than a rising time t_{dr2} due to the time constant circuit 4. As a result, a time period T_2 of high level (="1") of the binary signal S is longer than a time period T_1 of a high level of the binary signal S as shown in Fig. 3B.

Thus, $T_0 < T_1 < T_2$. Therefore, waveform distortion between a photocurrent and a binary signal and waveform distortion between different binary signals corresponding to different levels of photocurrents are generated.

A first embodiment of the photocurrent-to-binary signal conversion apparatus according to the present invention will be explained next with reference to Figs. 5, 6A, 6B, 6C, 7A, 7B, 8A and 8B.

In Fig. 5, which illustrates a first embodiment of the photocurrent-to-binary signal conversion apparatus according to the present invention, the reference voltage generating circuit 3 of Fig. 1 is connected to the output of the amplifier 2, not the input of the amplifier 2. Also, the time-constant circuit 4 of Fig. 1 is deleted, so that the reference voltage V_{ref} as the threshold voltage V_{th} is supplied directly to the comparator 5.

In Fig. 5, when no light signal is incident to the photodiode 1, no photocurrent I_{pd} flows therethrough. As a result, in the amplifier 2, since no current flows through the negative feedback resistor 22, the detection voltage V_d is the same as the voltage at the cathode of the photodiode 1. In this case,

$$V_d = V_{os1}$$

where V_{os1} is an offset voltage of the operational amplifier 21 depending the current of a constant current source (see: 211a of Fig. 10A) therein. Also, in the reference voltage generating circuit 3, since the negative feedback

resistor 32 and the constant current source 33 generate an offset voltage V_{os2}, the offset voltage V_{os2} is applied to the detection voltage V_d, so that the reference voltage V_{ref} (= V_{th}) is given by

$$V_{ref} \ (= \ V_{th}) = \ V_{os1} \ + \ V_{os2}$$

Thus, in the comparator 5, since $V_d < V_{th}$, the binary signal S is low (="0").

In Fig. 5, when a light signal is incident to the photodiode 1, a current I_{pd} flows therethrough. As a result, in the amplifier 2, the current I_{pd} flows through the negative feedback resistor 22, so that the detection voltage V_d is given by

$$V_d = V_c + I_{pd} \cdot R_f$$

where V_c is a voltage at the cathode of the photodiode 1; and R_f is a resistance of the negative feedback resistor 22. In this case, since $V_c < V_{os1}$,

$$V_d < V_{os1} + I_{pd} \cdot R_f$$

Also, in the reference voltage generating circuit 3, the offset voltage V_{os2} is applied to the detection voltage V_d, so that the reference voltage V_{ref} is given by

$$V_{ref} (= V_{th}) = V_d + V_{os2}$$

Thus, in the comparator 5, since $V_d > V_{th}$, the binary signal S is high (="1").

The operation of the photocurrent-to-binary signal conversion apparatus of Fig. 5 will be explained next with reference to Figs. 6A, 6B, 6C, 7A, 7B, 8A and 8B where two different photocurrents I_{pd1} and I_{pd2} (> I_{pd1}) flow through the photodiode 1 as shown in Fig. 6A.

As shown in Fig. 6B, detection voltage V_{d1} and V_{d2} in response to the photocurrents I_{pd1} and I_{pd2}, respectively, are outputted from the amplifier 2.

As shown in Fig. 6C, since the offset voltage V_{os2} is applied to the detection voltage V_d, a reference voltage

V_{ref2} ($=V_{th2}$) at $I_{pd} = I_{pd2}$ is lower than a reference voltage V_{ref1} ($=V_{th2}$) at $I_{pd} = I_{pd1}$.

Note that, as shown in Figs. 6B and 6C, since the detection voltage V_d of the amplifier 2 is supplied to the reference voltage generating circuit 3, the reference voltage V_{ref} ($=V_{th}$) has a delay time t_d determined by a time constant of the reference voltage generating circuit 3 as compared with the detection voltage V_d.

When the photocurrent I_{pd1} flows through the photodiode 1, the detection voltage V_{d1} crosses the threshold voltage V_{th1} at an angle of about 90° as shown in Fig. 7A. Therefore, as shown in Fig. 7B, a falling time t_{df1} is about the same as a rising time t_{dr1}. As a result, a time period T_1 of a high level ($="1"$) of the binary signal S is about the same as a time period T_0 of a high level of the photocurrent I_{pd}.

Also, when the photocurrent I_{pd2} flows through the photodiode 1, the detection voltage V_{d2} crosses the threshold voltage V_{th2} at an angle of about 90° as shown in Fig. 8A. Therefore, as shown in Fig. 8B, a falling time t_{df2} is about the same as a rising time t_{dr2}. As a result, a time period T_2 of a high level ($="1"$) of the binary signal S is about the same as a time period T_1 of a high level of the binary signal S as shown in Fig. 8B.

Thus, $T_0 \doteqdot T_1 \doteqdot T_2$. Therefore, waveform distortion between a photocurrent and a binary signal and waveform distortion between different binary signals corresponding to different levels of photocurrents are hardly generated.

Also, as shown in Figs. 7A and 8A, since the detection voltage V_d crosses the threshold voltage V_{th} at a large angle such as about 90° , the noise output of the comparator 5 caused by the jitter components of the detection voltage V_d and the threshold voltage V_{th} can be suppressed.

In Fig. 9, which illustrates a second embodiment of

the photocurrent-to-binary signal conversion apparatus according to the present invention, the amplifier 2 of Fig. 5 is replaced by an amplifier 2' where the operational amplifier 21 of Fig. 5 is replaced by an operational amplifier

5 21'. That is, the input of the reference voltage generating circuit 3 of Fig. 5, i.e., the non-inverting input of the amplifier 31 of Fig. 5 is connected to an intermediate stage of the operational amplifier 21' of the amplifier 2' having the same phase as that of the detection voltage V_d.

10 In more detail, as illustrated in Fig. 10A, which is a detailed circuit diagram of a first example of the amplifier 2' of Fig. 9, the operational amplifier 21' is constructed by a differential amplifier 211 having a constant current source 211a and an output amplifier 212 including a

15 push-pull output circuit. The detection voltage V_d is derived from the output amplifier 212, while the reference voltage generating circuit 3 is connected to the differential amplifier 211.

On the other hand, as illustrated in Fig. 10B, which

20 is a detailed circuit diagram of a second example of the amplifier 2' of Fig. 9, the operational amplifier 21' is constructed by a first inverter stage formed by a constant current source 213 and an N-channel MOS transistor 214, a second inverter stage formed by a constant current source 215

25 and an N-channel MOS transistor 216, and a final inverter stage formed by a constant current source 217 and an N-channel MOS transistor 218. The detection voltage V_d is derived from the final inverter stage, while the reference voltage generating circuit 3 is connected to the first inverter stage.

30 Thus, the input voltage of the reference voltage generating circuit 3 has the same phase as that of the detection voltage V_d, however, a delay time t_d' of the reference voltage $V_{ref}(= V_{th})$ as compared with the detection signal V_d is

smaller than the delay time t_d in the first embodiment.

The operation of the photocurrent-to-binary signal conversion apparatus of Fig. 9 is substantially the same as that of the photocurrent-to-binary signal conversion apparatus of Fig. 5, except for the above-mentioned delay time, so that the stability of the operation deteriorates a little due to the above-mentioned smaller delay time t_d'.

In Fig. 11, which illustrates a third embodiment of the photocurrent-to-binary signal conversion apparatus according to the present invention, a delay circuit 6 formed by a resistor 61 and a capacitor 62 is added to the elements of Fig. 9. That is, the delay circuit 6 is connected between the reference voltage generating circuit 3 and the comparator 5 of Fig. 9. As a result, the reference voltage V_{ref} is delayed by the delay circuit 6 as compared with the detection voltage V_d, to thereby generate the threshold voltage V_{th}. Therefore, a delay time t_d'' of the threshold voltage V_{th} as compared with the detection voltage V_d is comparable to the delay time t_d in the first embodiment. As a result, the stability of the operation is improved and is comparable to that of the first embodiment.

As explained hereinabove, according to the present invention, the waveform distortion between a photocurrent and a binary signal and the waveform distortion between different binary signals corresponding to different levels of photocurrents can be suppressed.